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ABSTRACT

Pretests and posttests on the topic of evolution through natural selection were administered to students in a college nonmajors' biology course. Analysis of test responses revealed that most students understood evolution as a process in which species respond to environmental conditions by changing gradually over time. Student thinking differed from accepted biological theory in that: (1) changes in traits were attributed to a need-driven adaptative process rather than a random genetic mutation and sexual recombination; (2) no role was assigned to variation within a population or differences in reproductive success; and (3) traits were seen as gradually changing in all members of population. Although students had taken an average of 1.9 years of previous biology courses, performance on the pretest was uniformly low; there was no relationship between the amount of previous biology taken and either pretest or posttest performance. Belief in the truthfulness of evolutionary theory was also unrelated to pretest or posttest performance. Course instruction using specially designed materials was moderately successfully in improving students' understanding of the evolutionary process. (Author)

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Research Series No. 165

STUDENT CONCEPTIONS OF NATURAL SELECTION AND ITS ROLE IN EVOLUTION

Beth A. Bishop and Charles W. Anderson

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Abstract

Pretests and posttests on the topic of evolution through natural selection were administered to students in a college nonmajors' biology course. Analysis of test responses revealed that most students understood evolution as a process in which species respond to environmental conditions by changing gradually over time. Student thinking differed from accepted biological theory in that (a) changes in traits were attributed to a need-driven adaptive process rather than random genetic mutation and sexual recombination, (b) no role was assigned to variation within a population or differences in reproductive success, and (c) traits were seen as gradually changing in all members of a population. Although students had taken an average of 1.9 years of previous biology courses, performance on the pretest was uniformly low; there was no relationship between the amount of previous biology taken and either pretest or posttest performance. Belief in the truthfulness of evolutionary theory was also unrelated to pretest or posttest performance. Course instruction using specially designed materials was moderately successful in improving students' understanding of the evolutionary process.

STUDENT CONCEPTIONS OF NATURAL SELECTION AND ITS ROLE IN EVOLUTION[1]

Beth A. Bishop and Charles W. Anderson[2]

For the science of biology, the theory of evolution provides a unifying framework within which many diverse facts are integrated and explained. For this reason, an understanding of modern biology is incomplete without an understanding of evolution. Consequently, despite current controversies, evolution is covered in most high school and college biology courses.

The idea of evolution (i.e., that species change over time) was around long before Darwin. What was lacking was knowledge of a plausible mechanism. It wasn't until Darwin painstakingly amassed and presented overwhelming evidence for evolution in combination with the believable mechanism of natural selection in his *Origin of Species* that the theory was generally accepted by biologists.

Following the rediscovery of Mendel's work in the early 1900s and the subsequent rise of genetics, a modern understanding of natural selection developed. Termed Neo-Darwinism, it represented a synthesis of Darwin's theory with Mendelian genetics (Mayr, 1972). The origin of new traits in a population was attributed to the random genetic processes of mutation and sexual recombination, whereas changes in the frequency of traits over time were attributed to natural selection leading to differential reproductive success. Because this new synthesis explained what Darwin could not (the

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[2] Beth A. Bishop is a graduate student in entomology at Michigan State University. Charles W. Anderson is co-coordinator of the Science Teaching Project and an assistant professor of teacher education at Michigan State University.

origin of novel traits and the inheritance of existing traits), the basic elements of the Neo-Darwinian synthesis are now accepted by most biologists.

This paper arose from our attempts to teach this theory. When we presented what seemed to us relatively simple and straightforward explanations of the Neo-Darwinian synthesis in a college nonmajors' biology course, it became apparent that many students were not achieving an adequate understanding of the mechanism of evolution. It was clear that these students did not understand, but the nature of their errors was not clear, and neither was the means of correcting them. We therefore applied the techniques of research on conceptual change in order to understand better the nature of our students' difficulties. Our long-term goal was to develop teaching materials and techniques that better helped students overcome those difficulties.

Both the research questions and the methodological techniques of this study are those of research on conceptual change in science, which has given rise to an extensive body of research on student conceptions of a variety of scientific topics (e.g., Helm & Novak, 1983). This body of research includes one previous study on students' understanding of evolution by natural selection (Brumby, 1984). This study differs from Brumby's in that we focus on a less scientifically sophisticated population of students (college nonscience majors rather than first year medical students) and in that we attempt to develop a more complete and systematic description of student conceptions.

The main purposes of this study were as follows:

1. To describe, as completely as possible, the conceptions held by college nonscience majors concerning the mechanism of natural selection and the factors responsible for evolutionary change,

2. To assess the effects of instruction on the conceptions held by students, including both previous high school and college biology instruction and our college nonmajors' biology course, and

3. To determine if student conceptions of natural selection were associated with student belief in the theory of evolution as historical fact.

Methods

Subjects

Subjects involved in this study were 176 college students who were enrolled during three successive quarters in a one-term, nonmajors' introductory biology course, which included instruction in evolution and natural selection. Students were given diagnostic tests both at the beginning and end of the course. In addition to essay and multiple-choice questions designed to reveal how students thought about natural selection, each test included a question asking students whether they believed the theory of evolution to be truthful. The pretest also included a questionnaire asking for the number and kind of science courses students had previously taken in high school and college. The tests were administered in a manner that allowed students to remain anonymous; test performance did not affect the grade they received in the course.

Test Development

Development of the diagnostic test was begun by extracting essential points from material on evolution and natural selection that students would use during the course: lecture material and readings from the required text. A pilot version of the test was then constructed and administered as a pretest to first-term students. This initial test was composed mostly of open-response questions designed to reveal how students understood evolution by natural selection. Student responses to this first test were analyzed. Patterns of student responses that appeared to differ from correct understanding as we had defined it (the scientific conception) were identified and used as the basis for hypotheses concerning the nature of students' conceptions.

At this point we began a cycle that involved the following: (a) the test was revised to include questions that would test our hypotheses about

student conceptions, (b) the revised test was field-tested with a new group of students, (c) student responses to test questions were coded (see below for development of the coding procedure), and (d) using the data thus generated, we again revised our hypotheses concerning the students' conceptions. As a result of this ongoing process, major revisions of the diagnostic test were made during the first term of the study. The number of open-response questions was reduced, and several multiple-choice questions were added. This revised test was first administered to the first-term students as a posttest. From this time on, only minor revisions were made. A copy of the final test can be found in the appendix.

Data collected from the first-term students were used primarily to revise our hypotheses about important issues and to develop test items. Although these data provided valuable descriptive evidence, they are not included in any quantitative analysis procedures.

This report is based on a data sample of 110 pretests and 90 posttests given during the final two terms of the study The students taking each test were a random sample of the students enrolled in the course.

Analysis of Student Responses

Analysis of student test responses involved three procedures: (a) development of a description of student conceptions, (b) development of a procedure for coding student responses to test questions, and (c) development of a means of assigning conception scores to each student on the basis of their test responses.

1. Development of a description of student conceptions. We identified three major issues involving evolution by natural selection on which students, by virtue of their test responses, appeared to hold alternate conceptions. In addition to written responses to test questions, two additional

sources were used to understand and describe student conceptions. First, volunteer students were interviewed. These students were asked to elaborate on the written answers they had given to test questions and to explain their reasoning. Second, we had access to written and verbal statements that students had made on course tests and in lecture and laboratory sections. By using all these sources we were able to describe student conceptions in detail and validate our inferences. For each of the essential issues identified earlier, we developed descriptions that contrasted the scientific conception with an alternate, naive conception commonly held by students.

2. Development of a coding procedure. A procedure for coding and classifying student responses to individual test questions was developed. Codes focused on clearly observable characteristics of student responses. In some cases, student responses to a single question were coded more than once, with each code focusing on a different aspect of the response.

The reliability of this coding scheme was checked by comparing the codes assigned to randomly selected student responses by two different coders. When disagreements between coders occurred, the coding procedure was modified to produce better agreement. The final version of the coding scheme (Bishop, 1984) was 100% reliable for all questions except 1 and 2 (see appendix), which required long explanations by students. These questions were coded by two different people who settled discrepancies by mutual agreement.

3. Development of conception scores. For each issue of evolution by natural selection, students were classified as holding the scientific conception, the naive conception, or neither. Conception scores are a means of determining which of these groups a student fell into. Each issue was addressed by several test questions. Questions (or aspects of a question) addressing a single issue were grouped together. Each coded response for

each question was then assigned two scores; the first represented the degree to which students making such a response held the scientific conception. The second score represented the degree to which students making such a response held the naive conception. The criteria for assigning a given score to a given response are listed on the following page.

Score	Nature of Response
+2	Response provides a clear statement that student believes in the issue
+1	Response allows inference that student believes in the issue
0	Response does not provide readily interpretable evidence concerning student's beliefs about the issue
-1	Response permits inference contrary to belief in the issue
-2	Response is clearly contradictory to the issue

Scores for both the naive and scientific conceptions were summed for each issue. The result was that each student was assigned a scientific conception score and a naive conception score for each issue. We classified students receiving a summed score of +2 or above as holding the particular conception on the issue in question. Students receiving a summed score of 0 or less were classified as not holding the conception. Students receiving a score of +1 were considered unclassifiable.

Assessing Effects of Instruction

The total number of years of biology instruction each student had taken prior to entering the biology course was determined on the basis of pretest questionnaires. Quarter-long biology courses were counted as one-third of a year; semester-long biology courses were counted as one-half of a year.

Students who had responded to the questionnaire were divided into three groups based on the number of years of previous biology instruction. Those who had taken two or more years of previous biology courses, those who had taken more than one year but fewer than two, and those who had taken one or fewer years of previous biology.

The effects of previous biology instruction were assessed by comparing the number of students in each group possessing the scientific conception (versus those not possessing the scientific conception) for each issue. Because previous biology instruction may affect not only what students know upon entering the course, but also what they learn during the course, the number of students in each group possessing the scientific conception on the posttest was compared in the same manner.

The effects of instruction in the biology course were assessed by comparing pretest conception scores with posttest conception scores. During the final two terms of the study, instructors were provided with materials specifically designed to promote conceptual change. These materials were designed to help students recognize the inadequacy of their misconceptions and develop appropriate scientific conceptions in their place. A module containing student handouts, lecture materials, problem sets, and a laboratory activity is available (Bishop & Anderson, 1986). Instruction on the process of natural selection took about one week in the ten-week course. There were also many references to evolution by natural selection at other points in the course.

Belief in Evolution

To test the hypothesis that beliefs about the truthfulness of evolution might affect, or be affected by, the conceptions students held, we divided responding students into three groups based on their answers to the question "Do you believe the theory of evolution to be truthful?" Believers were

those students answering yes to the above question. Nonbelievers were those students answering no. Unsure students were those who gave answers such as "I don't know", "partially," and the like. The number of students in each group possessing the scientific conception for each issue on the posttest was compared.

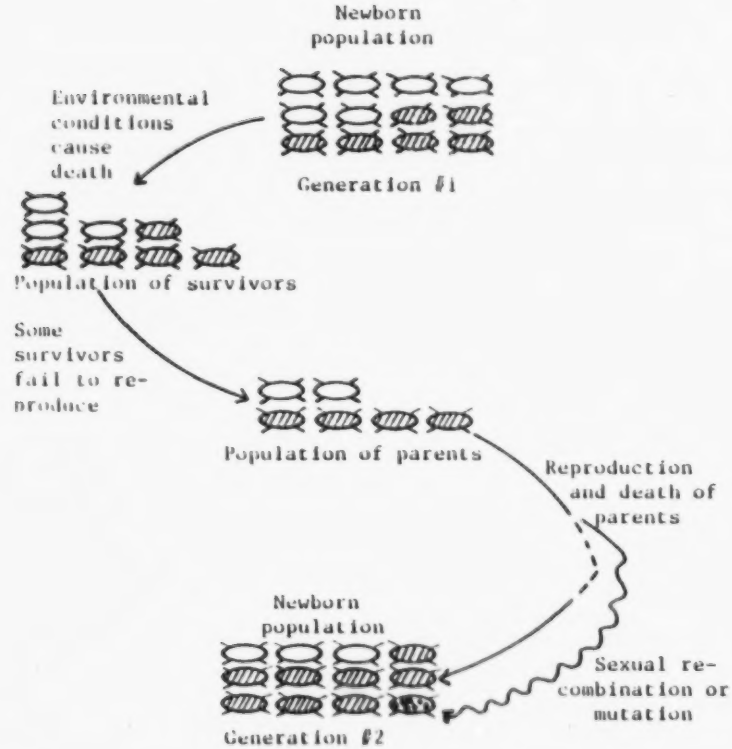
Results

Description of Student Conceptions

Most students entered the course believing they already had a basic understanding of the process of evolution by natural selection. Unfortunately, their ideas about how and why evolution occurred differed greatly from those accepted by biologists. In Figure 1, a generalization of students' naive conceptions is contrasted with the process as it is currently understood by biologists (scientific conception). We were able to identify three major ways in which student conceptions differed from the scientific conception. There are presented below as separate issues.

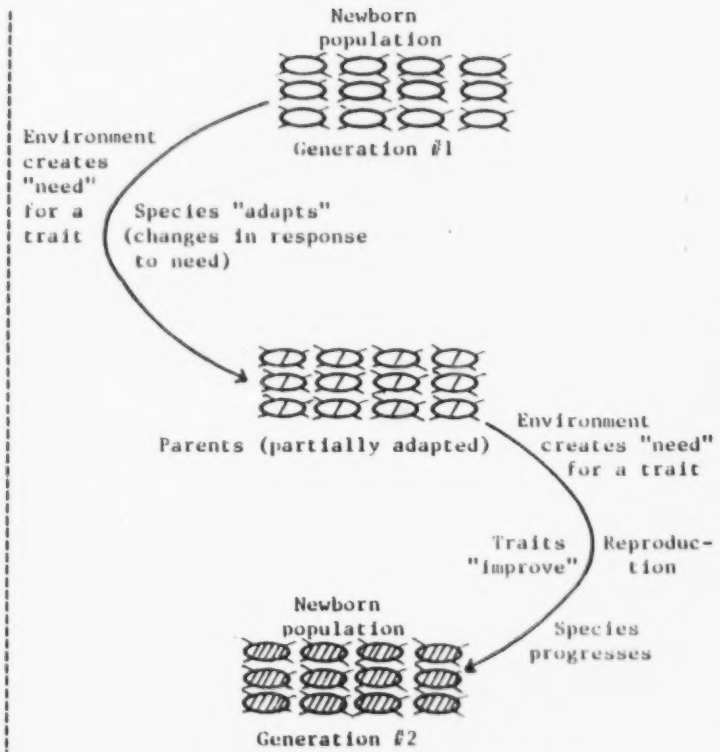
Origin and survival of new traits in populations. Biologists recognize that two distinct processes, fundamentally different in cause and effect, influence traits exhibited by populations over time. New traits (a) originate due to random changes in genetic material (random mutation or sexual recombination) then (b) survive or disappear due to selection by environmental factors (natural selection). Thus these two processes are depicted as separate occurrences on the left-hand side of Figure 1, which depicts the process of evolution as understood by biologists.

Many students fail to recognize the existence of two processes. Likewise, they fail to make a distinction between the appearance of traits in a population and their survival over time. Rather, they think a single process affects the development of traits in a species. On the right-hand side of



Non-random changes caused by death and failure to reproduce
Random changes occur during reproduction

SCIENTIFIC CONCEPTION OF EVOLUTION BY MEANS OF NATURAL SELECTION



Non-random (environmentally induced and directed) changes in traits possessed by the species as a whole

A GENERALIZATION OF STUDENTS' NAIVE CONCEPTIONS

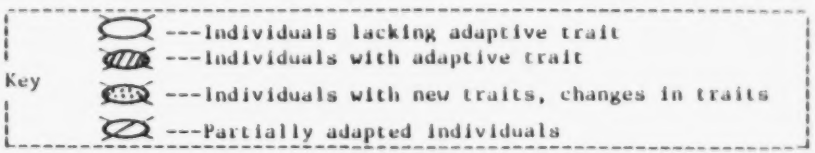


Figure 1. Comparison of scientific and naive understandings of the mechanism of evolution.

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Figure 1, which represents the naive conception, only one process is depicted as affecting traits. These students believe that the environment causes traits to change over time. Ideas about the mechanism by which the environment is believed to exert its influence include the following (examples given here come from student responses to Questions 1 and 2 on the test):

1. Need. Organisms develop new traits because they need them to survive. Example: "Because [cheetahs] needed to run fast for food, so nature allowed them to develop faster running skills."

2. Use and disuse. A species changes because its members use or fail to use certain bodily organs or abilities. Example: "Through nonuse of eyes for many generations, the eyes [of cave salamanders] became nonfunctional."

3. Adaptation. Many students use the word adapt in its everyday context (individuals changing in response to the environment) to explain evolutionary change. Example: "Biologists would say that through a slow adapting process the polar bear's coat would slowly change to white as a result of environmental factors."

We have found that difficulty in seeing how change can result from the combined effects of random mutation and nonrandom selection is an especially persistent problem. One reason for this perhaps lies in the simplicity and logical appeal of the naive conception. The presently accepted mechanism continues to be a subject of some controversy even within the biological community (e.g., Koestler, 1971; Keller, 1983). The students' naive explanations are implicitly Lamarckian: They imply that acquired traits can be inherited; however, we wish to emphasize that even students who rejected Lamarckianism often gave inadequate single-process descriptions of evolutionary change like those described above. We believe that they did this partly because they did not adequately understand the two-process alternative. Another reason, perhaps, for the appeal of this idea to students was their inability to distinguish causal from functional explanations. To many students, an explanation of the function of a certain trait to the individual is sufficient in and of itself to explain how the trait evolved. Thus the fact

that present-day porcupines need their quills to survive is taken as a sufficient explanation of how those quills evolved.

The role of variation within a population. Biologists believe that populations evolve because some individual members of a population possess a reproductive advantage, by virtue of their genetic traits, over other individual members. Thus, variation within populations is an essential precondition for evolutionary change. Students possessing naive conceptions did not view variability as important to evolution. Instead of focusing on a population composed of individual members, they viewed evolution as a process that molds or shapes the species as a whole. Example: "[Cheetahs] might have had to run fast to escape predators and gradually their muscles and bones changed to adapt to this."

Evolution as the changing proportion of individuals with discrete traits. Biologists believe that new traits arise through discrete genetic changes involving individual organisms. Those traits then gradually or progressively become established in a population, as the *proportion of individuals* possessing those traits grows with each succeeding generation. Students possessing naive conceptions attribute this gradual progressive quality not to proportion of individuals in population, but to *gradual changes in the traits themselves*, viewing traits as improving or deteriorating from one generation to the next. Example: "As sight was not needed, these salamanders in the cave, through generations, passed down genes with less ability to see until they had evolved to the blind ones."

This contrast can be seen by again comparing the left and right side of Figure 1. On the left side (scientific conception) the proportion of individuals with adaptive traits increases, but individuals do not change. On the right side (naive conception) each individual or descendent gradually adapts.

Confusing terminology. In addition to the major issues explained above, students' naive conceptions appear to be reinforced by their misunderstanding of two commonly used evolutionary terms: adapt/adaptation and fitness. Both of these terms have a meaning in everyday language that is different from their definition when used in an evolutionary context.

1. Adapt/Adaptation. To "adapt" means to change in response to something. When used in its everyday context, the word refers to altering, through their own efforts, their form, function, or behavior, as when a dog "adapts" to its new home. Biologists using the words "adapt" and "adaptation" in an evolutionary context are referring to a population phenomenon, whereby the *population* as a whole changes over many generations through the action of natural selection. The evolutionary process is driven by the reproduction and death of individuals, not by changes that occur during their lifetimes. Students hearing the word "adapt" in an evolutionary context, however, may construct meanings in terms of its everyday usage. This tends to reinforce the student conception explained earlier, of an environmentally directed influence on the appearance and development of traits.

2. Fitness. In everyday language, the term "fitness" is used to denote health, strength, and endurance. In an evolutionary context, the term is used to express the relative capability of individuals (or genes) to produce surviving offspring. In the evolutionary sense, any genetic trait that increases an organism's ability to produce surviving offspring also increases its fitness. Students operating within the former definition, however, often only recognize traits such as health, strength, and intelligence as contributing to fitness. This student conception tends to be reinforced by inaccurate popularizations of natural selection such as "only the strong survive."

There was a single question on the diagnostic test directed toward revealing student understanding of each of these terms. For each of the three

major issues, however, we had at least two questions. Because data based on a single question cannot be considered reliable, data on the terms "adapt/adaptation" and "fitness" are not included in the quantitative analyses presented below.

Effects of Previous Instruction

Virtually all of the students (96%) had taken some biology prior to entering the course. Ninety-three percent had at least one year of previous biology, and 38% had taken two or more years (N = 106).

Results showed that the amount of previous biology instruction had little or no effect on student conceptions. Table 1 shows the percentage of students in each group classified as understanding the scientific conception

Table 1

Relation Between Previous Biology Instruction and Student Understanding of Conceptions on Pretest and Posttest

Issue	Scientific Conception	Amount of Previous Biology					
		0-1 years (n =19)		1-2 years (n =37)		2 or more years (n =35)	
		Pre	Post	Pre	Post	Pre	Post
Origin and survival of new traits	Random processes responsible for appearance of traits; natural selection accounts for survival or disappearance	0	41	5	69	3	53
Role of variation within populations	Variable population essential for evolution	21	47	16	63	31	59
Evolutionary change	Involves changing proportions of individuals with discrete traits	0	47	16	66	17	57

on the pretest. All of the pretest percentages are surprisingly low. Even among those students taking two or more years of previous biology instruction, no more than 31% exhibited an understanding of any issue. These percentages are not significantly associated with previous biology courses for any of the issues. [Issue 1, chi-square = 1.19 (df = 2, p>.1); Issue 2, chi-square = 4.16 (df = 2, p>.1); Issue 3, chi-square = 3.30 (df = 2, p>.3).]

Neither did prior biology instruction seem to have an effect on the students' ability to learn the scientific conceptions during the biology course. Table 1 also shows the percentage of students in each group classified as believing the scientific conception on the posttest. Again, these percentages are not significantly associated with the number of previous biology courses for any of the issues. [Issue 1, chi-square = 3.73 (df = 2, p>.2); Issue 2, chi-square = 1.13 (df = 2, p>.3); Issue 3, chi-square = 1.25 (df = 2; p>.3).]

Instruction in the biology course was specifically geared toward producing conceptual change. All of the naive conceptions were directly confronted and contrasted with the corresponding scientific conception (Bishop & Anderson, 1986). Our results show that, though far from perfect, these methods were apparently more effective than previous biology instruction had been. Table 2 presents the percentage of total students taking the pretest and/or posttest who were classified as believing each conception. On the pretest, more students were committed to the naive than the goal conception for Issue 1 and Issue 2. The percentage of students classed as believing the naive and scientific conceptions were similar for Issue 3, with many students not firmly committed to either conception.

On the posttest, the percentage of students possessing the scientific conception increased to over 50% for each of the issues. The percentage of students possessing the corresponding naive conception decreased.

Table 2

Percentage of Student Understanding and Commitment to Three Important Issues

Issue	Conception	Percent of Students Committed to Conception	
		Pretest (N = 110)	Posttest (N = 90)
1. Origin and survival of new traits	Scientific: Random processes responsible for appearance of traits; natural selection accounts for survival or disappearance	3[a]	56
	Naive: Environmentally caused processes direct changes in traits	51	14
2. Role of variation within populations	Scientific: Variable population essential for evolution	23	57
	Naive: Change occurs to the species as a whole	30	14
3. Evolutionary change	Scientific: Involves changing proportions of individuals with discrete traits	15	57
	Naive: Involves progressive change in quality of traits as they are passed from one generation to the next.	12	8

[a]Totals are less than 100% because some students could not reliably be classified as committed to either conception.

These results indicate two things. First, the concepts of evolution by natural selection are far more difficult for students to grasp than most biologists imagine and, second, many students can change their naive conceptions on the subject if instructors are aware of them and prepared to confront them.

Effects of Belief in Evolution

Fifty-nine percent of students answering the question "Do you believe the theory of evolution to be truthful?" on the pretest were classified as believers, 11% were classified as nonbelievers, and 30% were unsure (N = 90). Answers to the same question on the posttest gave similar results: 49% believers, 26% nonbelievers, and 27% unsure (N = 57).

In general, student beliefs about the truthfulness of evolution were only slightly affected by instruction. Sixty-seven percent of the students who answered the question on both the pretest and the posttest (N = 32) did not change their answers. Of the 11 students who did change their answers, all did so between the unsure category and the believer or nonbeliever category. There were no changes from the believer to the nonbeliever category or visa versa.

Student conceptions were not associated with their belief (or lack of belief) in the truthfulness of evolution. Table 3 lists the percentage of students in each of the three groups categorized as possessing the scientific conception on the posttest. In fact, a slightly higher percentage of the non-believers possessed the goal conception, although this difference was not statistically significant for any of the issues. [Issue 1; chi-square = 2.38 (df = 2, p>.2): Issue 2; chi-square = 4.18 (df = 2, p>.3): Issue 3; chi-square = 3.17 (df = 2, p>.1).]

Table 3

Relation Between Belief in Evolution and Student Conceptions: Posttest

Issue	Scientific Conception	Percent of Understanding Scientific Scientific Conception		
		Believers (n = 28)	Nonbelievers (n = 15)	Unsure (n = 14)
1. Origin and survival of new traits	Random processes responsible for appearance of traits; natural selection accounts for survival or disappearance	50	73	64
2. Role of variation within populations	Variable population essential for evolution	57	73	36
3. Evolutionary change	Involves changing proportions of individuals with discrete traits	57	80	50

Implications

We believe that the most important contribution of this research lies in its description of students' naive conceptions about the process of natural selection. The research has produced both a structured description of student conceptions that identifies for instructors the most important sources of student difficulty with this topic and a diagnostic test that is relatively efficient and easy to use.

The results suggest that most presently used methods of teaching about evolution by natural selection are ineffective for this population of students. Even students who had taken two or more years of biology before taking the pretest generally showed little understanding of the evolutionary

process. The methods developed for the course (Bishop & Anderson, 1985), which were based on our analysis of students' conceptions, were more effective than the students' previous instruction, but still left substantial numbers of students without a working knowledge of evolution by natural selection.

The results of this research also have important social implications. If the students that we studied are taken as representative of college-educated nonscientists, then it appears that a majority of people on both sides of the evolution-creation debate do not understand the process of natural selection or its role in evolution. The results do not indicate, however, that better understanding would lead to a general acceptance of evolution. Students who improved their understanding of the process of natural selection did not generally change their convictions about the truthfulness of the theory. For most students, those convictions seem to be based more on social, religious, or metaphysical commitments than on an analysis of scientific evidence. This may be disturbing to biologists who would like for the general public to believe and appreciate the discipline's central theory, but it should be comforting to those who fear that instruction in evolution will cause children to abandon religious beliefs.

Finally, we would like to say a word about the prevalence of the naive conceptions in this well educated population. These results indicate that over half of this population possess naive conceptions about evolution. Why are these beliefs so prevalent? One answer seems to be the simplicity and logic of the naive ideas. It would be wonderful if organisms could simply acquire those features necessary for survival, but nature does not operate in this manner. A second reason may be the language used in popularizations of evolutionary history. Both film and written accounts often, in an attempt to simplify concepts for the lay public, use language that tends to reinforce

these misconceptions. Examples from well respected programs include such statements as these, "As the climate changed, the plants and animals had to adapt or face extinction" and "Only the smartest and strongest animals survived." While biologists might understand these statements correctly, the evidence is that the general public, for whom these programs are intended, do not.

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Evolution Concept Test

1. Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run 20 miles per hour?

2. Cave salamanders are blind (they have eyes which are nonfunctional). How would a biologist explain how blind cave salamanders evolved from sighted ancestors?

3. For the following questions, use the numbered statements listed and circle the number which most closely corresponds to what you understand.

    1 - The statement on the left is the only correct statement.
    2 - The statement on the left is more correct.
    3 - Both statements are equally correct.
    4 - The statement on the right is more correct.
    5 - The statement on the right is the only correct statement.

    If neither statement represents your understanding, please explain.

    Ducks are aquatic birds. Their feet are webbed and this trait makes them fast swimmers. Biologists believe that ducks evolved from land birds which did not have webbed feet.

    a) The trait of webbed feet in ducks

    Appeared in ancestoral ducks because they lived in water and needed webbed feet to swim. 1 2 3 4 5 Appeared in ducks because of a chance mutation

    Explain:

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5. Biologists often use the "fitness" when speaking of evolution. Below are descriptions of four male lions. According to your understanding of evolution, which lion would a biologist consider the "fittest?"

Name	"George"	"Ben"	"Spot"	"Sandy"
Size	10 feet 175 lbs	8.5 feet 160 lbs	9 feet 162 lbs	9 feet 160 lbs
Number of cubs fathered	19	25	20	20
Age of death	13 years	16 years	12 years	9 years
Number of cubs surviving to adulthood	15	14	14	19
Comments	George is very large, very healthy. The strongest lion.	Ben has the greatest number of females in in his harem.	When the area that Spot lived in was destroyed by fire, Spot was able to move his pride to a new area & change his feeding habits.	Sandy was killed by an infection resulting from a cut in his foot.

The "fittest" lion is:

a) George b) Ben c) Spot d) Sandy

Explain your answer:

6. Do you believe the theory of evolution to be truthful?_____
Why or why not?